

Saskatchewan

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Agriculture Development Fund

FINAL REPORT

**MANURE MANAGEMENT IN SASKATCHEWAN: A REVIEW
OF LITERATURE AND APPLICATION TO SASKATCHEWAN
CONDITIONS**

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Preface

The Agriculture Development Fund of Saskatchewan Agriculture and Food retained J.L. Henry to review the scientific literature on manure application to land, to review and critique current ADF funded manure management projects and to recommend research priorities for the future.

The project assembled 171 references in to a computer based Endnote file and 96 of those were utilized in the literature review. The report is structured so that a concise summary appears at the start of each section. A summary report is also provided which is a compilation of all the summary statements. A literature review and critique of this type does not lend itself well to the standard 'Executive Summary'. The reader who wishes to quickly glean the essence can read only the summary report and proceed to specific report sections if more detail is required.

A very brief summary is provided below for use in web sites.

Web Summary

A literature review utilized 96 scientific references and current research in Saskatchewan to develop priorities for future research. Data from many studies has shown that long-term sustainable manure applications require that the application rate be based on nutrient content. The nutrient application should not greatly exceed the nutrient uptake by crops on the land receiving the manure. Liquid hog manure is a dilute ammonium based nitrogen fertilizer and can be treated as such in agronomic recommendations. The ammonium content of liquid manure can be estimated in the field using electrical conductivity measurements.

Work on manure application technique in Saskatchewan has developed equipment to allow manure injection with minimum soil disturbance and temporary pipeline systems to deliver manure to remote fields without the need for large tanks that may harm roads.

Liquid hog manure has a high electrical conductivity and very high continuous rates could result in soil salinization. A specific concern about sodicity of manure where the feedstock water is sodic will require attention in the near future.

Any long term agronomic experiments must be based on agronomically feasible nutrient rate applications. There is no need to establish long-term plots with high manure rates - the result of such practice is well known from work in other jurisdictions. Any future agronomic work should determine the best sequence of rates to maximize crop production while avoiding environmental problems.

SUMMARY REPORT

1. Solid Manure

1.1. Historical Farmyard Manure Experiments

SUMMARY

All the long-term experiments on farmyard manure show it to be a 'slow-starter' as a fertilizer but to have long lasting positive effects on crop yield and soil fertility. All of the historical long term manure experiments show a significant increase in available soil P over the length of the experiment. The classical long-term manure experiments were typically conducted using 'farmyard manure' which was not well defined and probably had a large portion of straw used in bedding the animals. The product being used in those experiments was not the product now being generated by intensive livestock operations such as feedlots or liquid hog manure. Modern feedlots typically produce manure with a minimum of straw and hence the nutrient content is much higher.

1.2. The Modern Long-Term Feedlot Manure Experiment at the Agriculture and Agri-Food Canada Lethbridge Research Station.

SUMMARY

The long-term feedlot manure experiments at Lethbridge have shown that the maximum recommended annual rates of 30 T/ha for dryland and 60 T/ha for irrigation are not environmentally sustainable.

1.3 Solid Manure Studies in the United States

SUMMARY

Data from several states shows clearly that excessive annual applications of beef feedlot manure result in soil and groundwater nitrate problems, very high soil P which can lead to surface water problems and increases in soil salinity.

2. Liquid Manure

2.1 Data from Eastern Canada

SUMMARY

Data from Eastern Canada shows that liquid manure has a nitrogen fertilizer use efficiency only slightly less than urea. For Timothy hay large annual manure N applications left no soil residual N.

2.2 Data from the United States

SUMMARY

In North Carolina data liquid hog manure N rates at 2x the fertilizer N recommended rate for corn production was not problematic but 4x the recommended rate did cause problems.

Studies in Illinois, Wisconsin and Minnesota have shown that moderate N rates as liquid manure perform well but that very high loading rates result in nitrate and/or salt accumulations.

2.3 Liquid Hog Manure and Copper Concerns

SUMMARY

Dozens of experiments in UK, Europe and US have found no detrimental effect of Cu in manure based on 250 ppm Cu additions to the diet of pigs.

2.4 Liquid Manure and Veterinary Medicines

SUMMARY

A single paper on the topic provides a procedure to estimate residues of veterinary medicines in soil receiving manure.

3. Studies on Ammonia Volatilization from Surface Applied Manure and Effects of Incorporation

SUMMARY

* Volatile loss of ammonia from surface applications of manure is determined largely by environmental conditions. Conditions which favor rapid evaporation such as warm temperature, low humidity and high winds can result in substantial and rapid loss of half or more of the ammonium -N in the manure.

* Injection of manure greatly reduces volatile ammonia loss

* Incorporation of manure also greatly reduces volatile ammonia loss but under conditions of strong evaporation the time window is very narrow. If incorporation is not immediate, much of the benefit is lost. Immediate incorporation is easy to recommend but not practical on most farms.

4. Manure Applications and Soil Salinity

SUMMARY

* Beef feedlot manure from feedlots that use no bedding is a much different product than the farmyard manure on which original recommendations were made. The salt and nutrient content of manures must be utilized as the basis for setting safe rates of application for long term annual applications.

* Liquid hog manure has the potential to salinize land, but problems can be avoided by treating it as a fertilizer and applying the fertilizer based on major nutrient analysis and in relation to crop requirements.

* The $\text{NH}_4\text{-N}$ content of liquid hog manure can be easily determined in the field by measuring the EC of the manure.

* Where high SAR groundwater is used in hog operations the Na content of the manure will be high, but the SAR will be up only slightly. Some high manure Na values have also been found where the water used in the barn has a low SAR suggesting that ration is also

important. Most manure SAR values measured to date suggest that there should be no problem, but a few high SAR values have been encountered as a precautionary measure a program should be launched to sample soils that have received many annual applications of liquid hog manure where the water source for the operation is the Judith River Formation. The study should include an investigation of hog operations that produce high SAR manure to determine the role of water and ration in producing a high SAR.

5. Manure Nutrient Loading Rates

SUMMARY

Excess N from manure can result in nitrate accumulation in soils and leaching to aquifers used for drinking water. High nitrate drinking water can cause methemoglobinemia in babies. Excess P can accumulate in soil and move by erosion to surface water bodies and lead to eutrophication.

The N: P_2O_5 ratio of common crops is about 2.3 :1 but the N: P_2O_5 ratio for most livestock manures is 1:1. Therefore, over the long term, continual manure application to land will result in an accumulation of soil P even if the N is matched to crop removal.

In most jurisdictions loading limits are related to N at first and later the limits are based on P. Limits based on P are required where well developed drainage patterns deliver runoff from fields to sensitive water bodies.

It is unlikely that P limits will be needed in Saskatchewan in the near future. If it is needed in the future, it should be applied to areas draining directly to sensitive water bodies.

If P based soil loading limits were considered for Saskatchewan, a first approximation would be to limit further P additions to crop removal when soil test P in the 0-15 cm depth exceeds 60 ppm and to not apply any manure when soil test P in the 0-15 cm depth exceeds 100 ppm.

It is more likely that N limits will serve Saskatchewan the best.

Suggested annual manure N loadings for Saskatchewan are as follows:

Soil Climatic Zone(s)	Annual N rate (lbs N /ac)
Dry Brown	50
Brown	60
DarkBrown & Moist DarkBrown	70
Black & Moist Black	80
Grey	90
Irrigated	100

Suggested soil test limits for land receiving manure in Saskatchewan are as follows:

Soil	Soil Nitrate N Limit lbs/acre, 0-1 foot
Browns & Dark Browns	75
Blacks	100
Grey	125
Irrigation	150

6. Recommendations for Future Work

- (1) A high priority for future work should be to deal with the concern in Southwestern Saskatchewan about possible soil sodicity problems from manure where the water source is from wells completed in the high Na Judith River Formation.
- (2) There is no need to establish any long-term study with beef feedlot manure. That work has been done and is ongoing at Lethbridge and does not need to be repeated in Saskatchewan.
- (3) There is no need to establish a long-term experiment with high rates of liquid hog manure. It is well known that rates much higher than crop uptake will result in soil and groundwater nitrate accumulation. A single long-term experiment with reasonable rates of liquid hog manure could be beneficial.
- (4) ILOs that have been in operation for decades should be selected and detailed soil samples taken to determine long-term effects. One or two locations with sensitive hydrologic environments could be selected to determine the nature of contaminant plumes of nitrate from manure.
- (5) The work already conducted on EMS structures should be summarized and interpreted before any new studies are commissioned.
- (6) The project related to water runoff should be re-focused and integrated with information related to possible human pathogens from manure. The recent events in Ontario should result in such a project being elevated to a high priority.
- (7) The engineering work on low disturbance injection and pipeline distribution is of a very high priority. The research and demonstration work on these aspects should receive high priority until such time as the technology is commonplace on land receiving liquid manure.
- (8) A protocol should be established for salinity analysis of manure so that the data necessary for sodicity interpretations is available.



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1. Solid Manure

1.1. Historical Farmyard Manure Experiments

SUMMARY

All the long-term experiments on farmyard manure show it to be a 'slow-starter' as a fertilizer but to have long lasting positive effects on crop yield and soil fertility. All of the historical long term manure experiments show a significant increase in available soil P over the length of the experiment. The classical long-term manure experiments were typically conducted using 'farmyard manure' which was not well defined and probably had a large portion of straw used in bedding the animals. The product being used in those experiments was not the product now being generated by intensive livestock operations such as feedlots or liquid hog manure. Modern feedlots typically produce manure with a minimum of straw and hence the nutrient content is much higher.

In the past, Agriculture Canada Research stations at Melfort and Indian Head have conducted long-term agronomic experiments with farmyard manure. The data from those experiments has been summarized (McIver *et al.* 1978).

The Indian Head experiment was on an Indian Head clay soil and went from 1948 to 1976 with wheat as the test crop in a three year fallow-wheat-wheat rotation. The manure was applied in the spring of the fallow year at rates of 0, 13, 20 and 27 ton/ha. For the first decade wheat yield responses to the manure application were only about 2 bus/acre but after that time yield increases went up sharply to about 10 bus/acre.

The Melfort experiment was on a Black loam soil at Parkside and ran for 37 years. A rate of 37 ton/ha of manure was applied every 5 years in a 5 year grain forage rotation. For the first 20 years of the experiment wheat yield responses to manure were about 7 bus/acre but the yield response went up sharply to about 12 bus/acre in the last decade of the experiment.

At the 1978 Ottawa Work Planning meeting, Theron Sommerfeldt of Agriculture Canada Lethbridge reported on an experiment where 70 T/ha of manure had been applied annually to a Brown loam soil (Sommerfeldt 1978). The build up of nutrients was not considered objectionable, but was maintaining the soil in a good state of fertility.

The long term Manitoba data on barnyard manure also showed small responses in the first decade and larger responses in the final years of experiments that ran for 35 years (McGill 1978).

1.2. The Modern Long-Term Feedlot Manure Experiment at the Agriculture and Agri-Food Canada Lethbridge Research Station.

SUMMARY

The long-term feedlot manure experiments at Lethbridge have shown that the maximum recommended annual rates of 30 T/ha for dryland and 60 T/ha for irrigation are not environmentally sustainable.

Prior to setting up the Lethbridge long-term experiments, sampling was conducted on soils and waters around existing feedlots. That data showed a buildup of soil nutrients but no environmental problems from 40 years of annual applications of 70 T/ha of manure to an irrigated Brown loam soil (Sommerfeldt *et al.* 1973). At that time the recommended maximum rate of manure application for irrigated land in Alberta was 56 to 67 T/ha.

In 1973 the Lethbridge long-term feedlot manure experiments were established [Sommerfeldt, 1985]. To prepare this review of the Lethbridge study all the scientific papers about the study were assembled in chronological order. The following account will proceed through the papers in chronological order. **In April, 2000 the author of this review visited the field plots at Lethbridge to view the actual layout of the experiments and discuss the project with the current generation of workers.**

The relevant facts of the Lethbridge long-term feedlot manure experiments are:

- Location:** Agriculture Canada Research Station at Lethbridge
- Soil:** Dark Brown loam, about 120 to 150 cm lacustrine over till
- Plot size:** 23m x 61m
- Manure rates-** applied on an annual basis to the same plots
 - 0,30,60,90 T/ha wet weight for dryland treatments
 - 0,60,120,180 T/ha wet weight for irrigated treatmentsAt the time the experiments were started the maximum recommended annual rates were 22 to 27 T/ha for dryland and 56 to 67 T/ha for irrigated land.
- **Manure source:** a feedlot near Coaldale, Alberta and the manure has come from the same feedlot for the entire length of the experiment which is still in progress. No bedding was used in the feedlot (Chang *et al.* 1991).

After the experiments had continued for about 10 years it was concluded that "the relatively low rates that are currently recommended, can maintain and increase the organic matter content of the soil and ameliorate the physical condition of southern Alberta soils" (Sommerfeldt and Chang 1985). The starting soil organic matter (OM) content was 2.1% and by 1981 the maximum manure rate for the dryland treatment had 4.1% OM and the maximum manure rate for the irrigated treatment had 6.5% OM. **After 10 years all was well and the manure was improving the soil.**

In 1985 the Lethbridge data was used as the basis for a computer model to calculate break-even hauling distances for feedlot manure based on the crop response to the N and P in the manure. That analysis suggested that custom corral cleaners could be

used to haul up to 18 km and smaller operations could afford to haul 15 km (Freeze and Sommerfeldt 1985)

In 1986 detailed aspects of soil OM and available P were examined and it was concluded that detrimental effects had not been measured after 10 years of high manure rates (Dormaar and Sommerfeldt 1986). However, the authors went on to say "We cannot be complacent about this. To establish criteria for feedlot manure disposal, we will have to continue the project until detrimental effects are observed, so that boundaries can be established". The wisdom of that statement will soon be apparent.

In 1987 a report on soil-water properties showed that the manure had no effect on infiltration rates or saturated hydraulic conductivity but that plant available water was reduced by manure (Sommerfeldt and Chang 1987). The reduction in plant available water was due to an increase in soil water at Wilting Point rather than a decrease at Field Capacity.

In 1988 the accumulation of OM and N was described by mathematical equations which could be used to predict how the accumulation would proceed. The rates of accumulation decreased such that after two or three decades further increases would be small (Sommerfeldt *et al.* 1988).

The 1987 and 1988 papers presented data that is summarized in Table 1. As expected the soil OM reached higher levels under irrigated conditions and at the highest manure rates were similar to Black soils.

Table 1. Soil OM after 12 years of annual manure applications of beef feedlot manure (Sommerfeldt and Chang 1987).					
DRYLAND			IRRIGATED		
Annual Manure T/ha	Total N Applied kg/ha	Soil OM %	Annual Manure T/ha	Total N Applied kg/ha	Soil OM %
0	0	2.1	0	0	2.2
30	3088	3.0	60	6203	4.1
60	6171	3.7	120	12251	6.2
90	9261	4.4	180	18384	7.9

The above data for total N applied suggests that some environmental problems would be expected soon. The lowest rate of manure application under dryland gave an annual application of $3088/11 = 280 \text{ kgN/ha}$ and the maximum rate under irrigation gave an annual application of $18384/11 = 1075 \text{ kgN/ha}$.

In 1990 soil chemical changes after 11 annual manure applications were documented (Chang *et al.* 1990). That paper reported the average saturated paste EC of the manure as 23 mS/cm and the SAR was 22. The 1990 analysis of the data concluded that **"sustained agricultural production of this land with manure is in question , and the potential for problems due to leaching of various soluble salts and nutrients to groundwater is increased"**.

In 1991 soil chemistry after 11 annual manure applications was summarized (Chang *et al.* 1991) as follows:

Soil pH : decreased by about 0.5 pH units at the maximum manure rate

Soil EC (sat.paste) increased from 1 mS/cm for the control to 6 at the maximum manure rate

Soil SAR increased from 0.5 for the control to 4 at the maximum manure rate.

By 1991 it was concluded that **" Long-term annual application of cattle manure to southern Alberta soils at maximum recommended rates (30 T/ha for dryland and 60 T/ha for irrigated) is not advisable"** (Chang *et al.* 1991).

In 1993 and 1994 the effect of 16 continuous years of manure application on barley yield was reported (Chang *et al.* 1993).

Under dryland conditions barley grain yield was reduced by high manure rates in dry years. The 60 T/ha rate reduced barley grain yield by 10 % and the 90 T/ha reduced yield by 16%. Under irrigation the 60 T/ha manure rate increased barley grain yields by 20 % (Chang *et al.* 1993). Under irrigation the 0 manure plots yielded 3920 kg/ha barley grain (73 bus/acre) on average from 1974 to 1989 suggesting that the soil was highly fertile at the start of the experiment.

Under **dryland**, barley grain **protein** was 14.3 % with no manure and 17.5% with the highest rate. Under **irrigation** , barley grain **protein** was 11.2 % with no manure and 15.7% with the highest rate (Chang *et al.* 1993).

The high rates of manure did not suppress uptake of copper or zinc by barley, despite very high soil P levels (Chang *et al.* 1994).

In 1996 the nitrate leaching losses from manure applications were determined and published (Chang and Entz 1996). Under dryland conditions nitrate was leached below 1.5 m only in 1978 when precipitation was very high. Under **irrigation** there were large **nitrate leaching losses** reaching annual values as high as 341 kg N/ha.

A further analysis of the fate of nitrogen from feedlot manure applications showed that under dryland conditions the added N could be accounted for by crop uptake and soil residuals but with irrigation there were appreciable leaching and volatilization losses (Chang and Janzen 1996).

In summary, the long-term feedlot manure experiments at Lethbridge have shown that the maximum recommended annual rates of 30 T/ha for dryland and 60 T/ha for irrigation are not environmentally sustainable.

1.3 Solid Manure Studies in the United States

SUMMARY

Data from several states shows clearly that excessive annual applications of beef feedlot manure result in soil and groundwater nitrate problems, very high soil P which can lead to surface water problems and increases in soil salinity.

TEXAS

A 3 year experiment with cattle feedlot manure at Bushland Texas on a Pullman clay loam soil, found that 22 T/ha of manure annually (the lowest rate studied) gave adequate nutrients for maximum yields of irrigated corn silage (Mathers and Stewart 1974). That study included rates of 0, 22, 45, 112, 224, 448 and 896 T/ha wet weight of manure. The 448 and 896 rates were discontinued after only two years because the negative effects of soil salinity and nitrate accumulation were already evident. The 22 T/ha rate provided 300 hg/ha of nitrogen. Rates higher than 22 T/ha caused nitrate and salt accumulation and raised the nitrate level in corn silage to unacceptable levels (Mathers and Stewart 1974).

The Texas experiment was extended to a 14 year period including 11 applications of 22 T/ha of manure and less frequent applications of higher rates (Mathers and Stewart 1984). Crops grown over the 14 year period included sorghum, corn and wheat. The study showed that annual applications of 22 T/ha manure was adequate to meet the nutrient needs of irrigated crops and that 67 T/ha or greater resulted in salt or ammonia damage to seedlings and nitrate leaching from the soil profile (Mathers and Stewart 1984).

KANSAS

An early study with feedlot manure in Kansas showed that 20 tons/acre provided the N required for optimum yields of irrigated grain sorghum in the year of application and showed residual effects for 3 years (Herron and Erhart 1965). That study established that each ton of feedlot manure was equivalent to 22 lbs of N from ammonium nitrate fertilizer. Each ton/acre of feedlot manure increased soil test P in the 0-6 inch layer by 2 lbs/acre. In the Kansas study the manure used had 31-9-16 lbs/ton of N,P and K respectively, which was compared to normal 'farmyard manure' with bedding that commonly is assumed to be 10-5-10 (Herron and Erhart 1965).

In 1969 an experiment was started on a silty clay loam soil near Pratt, Kansas to determine effects of very high rates of beef feedlot manure on irrigated corn. The rates after 4 years ranged from 114 to 2,750 T/ha of dry manure. The soil EC was increased linearly with manure rate and reached values more than 10 mmho/cm for the saturated paste extracts (Wallingford *et al.* 1975a). **Rates of 29 to 68 T/ha /year of dry manure gave near maximum yields without excessive salt accumulation in the soil.** However, it should be noted that the **experiment only ran for 4 years.**

In another Kansas study beef feedlot manure or beef feedlot lagoon water were shown to be sources for the trace elements Fe, Zn and Mn and could be used to overcome deficiencies of those nutrients (Wallingford *et al.* 1975b).

CALIFORNIA

A 9 year study in California measured the effects of feedlot manure at total rates up to 540 T/ha applied as 3 annual 180 T applications. At the high rates only 42% of the N could be accounted for and soil test P values (NaHCO_3) were still 127 ppm in the 0-30 cm depth 5 years after manure applications had ceased (Meek *et al.* 1982). Exchangeable K was increased by the high manure rates but there was no measurable effect on exchangeable Na.

SOUTH DAKOTA

A recent survey of feedlot operators in South Dakota showed an average manure N application rate of 73 lbs/acre and an average P rate of 31 lbs/acre (Taylor and Rickerl 1998). Only 24 % of operations applied more than 100 lbs N/acre and only 5 % had manure N rates that exceeded 250 /acre. As would be expected, the larger feedlots applied the higher rates (Taylor and Rickerl 1998).

COLORADO

Very large cattle feedlots have been present in the state of Colorado for decades. As early as 1967 there were 621,000 cattle in feedlots in the South Platte River valley in Colorado (Stewart *et al.* 1967). A soil sampling study at that time showed large quantities of nitrate in the soil profile under feedlots but concluded that denitrification would prevent much of the nitrate from reaching the water table (Stewart *et al.* 1967).

The state of Colorado now has about 1 million cattle on feed at any one time. Recent studies of the South Platte River Basin's shallow alluvial aquifer show 70% of wells with nitrate above the safe limit (Dubois 1994) as reported by (Davis *et al.* 1997).

A recent study in Colorado sampled 41 corn fields located within 5 miles of a feedlot and which had received manure applications for several years (Davis *et al.* 1997). The soils were sample to a depth of 4 feet. There were 22 sites on sandy soils with annual manure rates varying from 18 to 30 T/ha and 19 sites on clay soils with annual manure rates varying from 44 to 77 T/ha. The conclusions from the study were as follows:

- No pH values above 8.0 or EC values above 4.0 mmhos/cm were recorded, but the potential exists for salinity problems on heavy soils.
- **Residual nitrate** was **300 lbs N/acre** in sandy soils and **396 lbs N/acre** on clayey soils
- **Soil P** levels were **Very High** and potential for P runoff with soil sediments was high (Davis *et al.* 1997).

A recent summary paper pointed out that two-thirds of beef cattle feeding occurs in Nebraska, Kansas, Iowa and Colorado and that 50 % of manure N is lost before removal from the feedlot and 50% of the remaining N is lost in handling and application (Eghball and Power 1994). That paper concluded that acceptable soil loading rates had not been defined and it was uncertain if loading rates should be based on N or on P buildup in soils.

2. Liquid Manure

There is a large quantity of published information concerning liquid manures from various species of livestock but most of the studies are short term and deal primarily with the agronomy of the N and P in the manures.

2.1 Data from Eastern Canada

SUMMARY

Data from Eastern Canada shows that liquid manure has a nitrogen fertilizer use efficiency only slightly less than urea. For Timothy hay large annual manure N applications left no soil residual N.

A study at Guelph, Ontario compared liquid poultry, liquid dairy cattle and solid beef manure with urea fertilizer as nitrogen sources for corn. The study included rates up to 300 kg N/ha and was continued for 3 years, but new sites were selected each year so no cumulative or residual data are available. The studies showed that 89 % of N in liquid poultry manure and 53 % of N in liquid dairy manure was as NH_4^+ . However, only 75 - 80 % of the ammonium-N was as effective as urea-N (Beauchamp 1986; Paul and Beauchamp 1993)

A study at MacDonald College in Quebec compared liquid hog manure to fresh or composted cow manure for corn production at rates of 0, 120 and 240 kg N/ha. The liquid hog manure had higher total crop N uptake and higher residual $\text{NO}_3\text{-N}$ levels in the soil (Xie and MacKenzie 1986)

A somewhat longer term study in Quebec involved 9 annual applications of liquid hog manure at 5000 and 10,000 gallons/acre. After the 9 applications there was no change in soil pH, total-N content or C:N ratio but soil microorganisms including nitrifiers were greatly increased (Ndayegamive and Cote 1989). The nitrogen

mineralization potential was doubled by the 10,000 gallon/acre rate but not affected by the 5,000 gallon/acre rate.

Further work at MacDonald College showed that liquid hog manure at 200 and 400 kg N/ha for 3 years doubled the yield of Timothy hay with very little residual increase in soil NO₃-N (Warman 1986)

2.2 Data from the United States

SUMMARY

In North Carolina data liquid hog manure N rates at 2x the fertilizer N recommended rate for corn production was not problematic but 4x the recommended rate did cause problems.

Studies in Illinois, Wisconsin and Minnesota have shown that moderate N rates as liquid manure perform well but that very high loading rates result in nitrate and/or salt accumulations.

NORTH CAROLINA

North Carolina has a large hog population with limited land base so has long ago recognized the need for research to determine loading rates for liquid hog manure. At Raleigh, North Carolina an 11 year experiment with liquid hog manure applied to 'Coastal' Bermudagrass has been reported in detail (Burns *et al.* 1990; Burns *et al.* 1985; Burns *et al.* 1987; King *et al.* 1990; King *et al.* 1985).

The North Carolina study involved annual liquid hog manure applications at rates to supply 335, 670 and 1340 kg N/ha each year for 11 consecutive years. To put the N rates in perspective one must consider the area where the study was conducted. For the high yield potential, high rainfall and long season in North Carolina, the recommended annual N fertilizer rate is about 335 kg N/ha so the rates of manure were at the recommended rate and 2x and 4x the recommended rate.

Not surprisingly some problems occurred at the highest rate of application. The high rate of 1340 kg N/ha /year resulted in forage nitrate contents at toxic levels in summer harvests and resulted in fluxes in stand composition, although the stand did recover (Burns *et al.* 1990). The high rate also resulted in appreciable NO₃-N accumulation in the soil to the 2.1m depth of sampling and much was probably lost to leaching to lower depths; soil P was increased to a depth of a (King *et al.* 1990).

ILLINOIS and MINNESOTA

An early Minnesota study examined the effect of very high applications of liquid hog and other manures (Evans *et al.* 1977). Only the liquid hog data will be discussed here. The field study applied liquid hog manure with an EC of 4.96 mmhos/cm at a rate of 636 T/ha for two consecutive years to a silt loam soil and the effects on corn crops and soil were studied for two additional years. The rate supplied 2400 kg N/ha in each of the two years for a total of 4800 kg N /ha.

That extremely high rate caused temporary wilting of corn because of localized high salinity levels, and high nitrate in corn stover, but otherwise corn growth was normal. Not surprisingly, NO₃-N was found below 150 cm by the end of the second crop year (Evans *et al.* 1977). The study area receives 20 inches of rain during months when the soil is not frozen. The high rates also increased the soil EC to a depth of 120 cm.

Growth chamber work with knife injection of liquid beef manure in Illinois and Minnesota had suggested detrimental concentrations of ammonia in the injection zone as a potential problem (Sawyer and Hoeft 1990; Schmitt *et al.* 1992). Further field investigations showed that the problem was related to N deficiency of corn that was not directly over the liquid manure band (Sawyer *et al.* 1991).

WISCONSIN

A Wisconsin study compared injected liquid dairy manure to broadcast ammonium nitrate with N rates of 84, 168 and 252 kg N/ha for 3 consecutive years (Comfort *et al.* 1987). The manure N rates were calculated to provide the same level of available N assuming all of the NH₄⁺ and 30 % of the organic N would be available in the year of application. They found more inorganic N in the soil profile and faster downward movement with the ammonium nitrate than the manure and attributed the difference to greater denitrification of manure N (Comfort *et al.* 1987).

2.3 Liquid Hog Manure and Copper Concerns

NOTE: This review deals only with copper. If information is required for other metals it is available in a literature review from Ontario (Webber and Webber 1983). That study concluded that it was very unlikely that land application of manure represents a significant micronutrient or heavy metal hazard to waters.

SUMMARY

Dozens of experiments in UK, Europe and US have found no detrimental effect of Cu in manure based on 250 ppm Cu additions to the diet of pigs.

United Kingdom and Europe

The addition of copper sulphate to hog rations to increase weight gains, feed conversion and profitability has been a standard practice in the United Kingdom and Europe since 1955. The standard rate of Cu addition is 250 mg Cu/kg of diet. By 1980 enough experience had been gained to convene a symposium at Bordeaux, France entitled "Copper in Animal Wastes and Sewage Sludge". That symposium included 25 scientific papers from many countries and the proceedings were published (L'Hermite and Dehandtschutter 1980).

The only problem resulting from land application of liquid hog manure containing copper was from situations where slurry was spread on standing forage crops which were then grazed by sheep, particularly lambs. The precautions noted to prevent the problem included:

- * applying the slurry when the grass was short
- * allowing a reasonable length of time between slurry spreading and grazing (L'Hermite and Dehandtschutter 1980) , page 252.

United States

A 4 year study in Indiana found no detrimental effects on corn production or the silt loam soil used by annual applications of up to 240 T/ha of swine manure from pigs fed a diet supplemented with up to 250 mg Cu /kg of diet (Sutton *et al.* 1983). The maximum Cu addition in the manure was 15.3 kg Cu/ha /year for each of the 4 years of application. While detrimental crop or soil effects were not found they did find that available soil Cu increased by about 3ppm each year and that problems would eventually occur with uninterrupted annual applications (Sutton *et al.* 1983).

An 11 year study with copper enriched swine manure was conducted in Virginia and has been extensively reported in the scientific literature (Anderson *et al.* 1991; Miller *et al.* 1986; Mullins *et al.* 1982; Payne *et al.* 1988; Zhu *et al.* 1991). The study compared Cu enriched manure to identical rates of Cu as copper sulphate. A cumulative addition of 325 kg Cu /ha from manure had no detrimental effect on corn growth or yield whereas Cu from copper sulphate did stunt the corn plants without reducing grain yield (Anderson *et al.* 1991). It was concluded that the soil organic matter increase associated with the manure applications was at least in part responsible for the lack of effect of copper additions on corn crops.

Copper in Saskatchewan Liquid Hog Manure

Based on analysis supplied by Jeff Schoneau liquid hog manure in Saskatchewan contains about 0.02 lbs Cu/1000gallon with a maximum value from one barn at 0.14 lbs Cu/1000 gallons.

2.4 Liquid Manure and Veterinary Medicines

SUMMARY

A single paper on the topic provides a procedure to estimate residues of veterinary medicines in soil receiving manure.

In commissioning this study ADF had requested information on antibiotics and hormones in pig diets and possible environmental consequences. The author of this review has no expertise in veterinary medicines but agreed to conduct a computer aided search for information. That search produced a single reference. The reference is of a generic nature and provides a procedure that can be used to estimate residues of medicines in soil (Spaepen *et al.* 1997). The title of the reference is "A uniform procedure to estimate the predicted environmental concentration of the residues of veterinary medicines in soil".

The paper outlines a series of steps to estimate the concentration of a particular medicine that would end up in the soil receiving the manure (PEC = Predicted Environmental Concentration).

Step1 : Determines the amount of active ingredient in the diet

- Step 2 : Calculates the concentration of the ingredient in the manure, assuming it is all excreted
- Step 3: Determines the maximum amount of manure that can be applied according to current European regulations
- Step 4: Calculates the rate of active ingredient that will be applied per unit area of land
- Step 5: Calculates the concentration of the active ingredient in the soil based on the depth of plowing. If the manure is not plowed in, the active ingredient is assumed to be distributed over a 5 cm depth of soil (Spaepen *et al.* 1997).

The above paper provides a model for evaluation of a particular intensive livestock operation with respect to concentration of veterinary medicines. At the time of writing the paper there was no field validation of the model. It was concluded that the model "should serve as a regulatory screening instrument allowing identification of veterinary medicines with a high potential for exposure to the environment" (Spaepen *et al.* 1997).

3. Studies on Ammonia Volatilization from Surface Applied Manure and Effects of Incorporation

SUMMARY

*** Volatile loss of ammonia from surface applications of manure is determined largely by environmental conditions. Conditions which favor rapid evaporation such as warm temperature, low humidity and high winds can result in substantial and rapid loss of half or more of the ammonium -N in the manure.**

*** Injection of manure greatly reduces volatile ammonia loss**

*** Incorporation of manure also greatly reduces volatile ammonia loss but under conditions of strong evaporation the time window is very narrow. If incorporation is not immediate, much of the benefit is lost. Immediate incorporation is easy to recommend but not practical on most farms.**

EASTERN CANADA

Studies at Guelph and MacDonald College have examined the issue of ammonia volatilization from surface applied manure.

In a Guelph study from 24 to 33 % of ammonia N applied in liquid dairy manure was lost to volatilization over one week in early May (Beauchamp *et al.* 1982). The study was conducted for 4 years and the N applied varied from 280 to 387 kg N/ha and the ammonium-N % of total manure N varied from 46 to 61 %.

An experiment at MacDonald College in Quebec found 25% of N was volatilized from surface application but only 10 % for injected manure, where the manure N rate was about 400 kg N /ha (Hengnirun *et al.* 1999). The Quebec study included the development of a model to predict volatile losses.

Other work at MacDonald College has examined the effect of manure additives on volatile loss of N (Al-Kanani *et al.* 1992; Subair *et al.* 1999). They found that calcium carbonate addition increased volatile losses but sphagnum peat moss reduced ammonia losses by 75%.

UNITED STATES

A very early paper from Wisconsin reviewed European literature on volatile loss of manure and conducted detailed laboratory studies where environmental conditions could be controlled (Heck 1931). That study showed that an 8.5 mile per hour wind resulted in volatile loss of 49% of the ammonia in manure when the comparable loss with no wind was only 15%. That study summarized the data as follows: "Greatest spreading losses occur when weather conditions are best for drying. Warm, dry, sunny days with wind produce conditions which cause greatest losses. If the spreading is done during cool, rainy weather and the manure incorporated with the soil immediately, the losses may be reduced to a minimum" (Heck 1931).

A Delaware laboratory study with poultry manure found about 10% volatile loss of applied NH_4^+ -N with immediate incorporation, 25% loss with incorporation after 1 day and 50 % loss if incorporation was delayed for 3 days (Schilke-Gartley and Sims 1993).

Work with solid dairy manure in New York State found that as much as 85% of the ammonia-N in the manure could be lost to volatilization (Lauer *et al.* 1976). The manure had only about 25% of the total N as ammonia and the largest losses were under environmental conditions conducive to rapid evaporation. Plowing down the manure within 6 days did not prevent large volatile ammonia losses.

Field studies with liquid swine manure at Purdue University in Indiana found only 11 to 14 % of ammonia -N volatilized from surface applications and only 2.5% loss for injected manure (Hoff *et al.* 1981). The field soil had pH of 6.4 and the manure applied had a pH of 6.4. The same study found 65% of ammonia-N volatilized in a laboratory experiment with a soil pH of 7.0 and manure pH of 7.8. Soil and manure pH and environmental conditions were concluded to be two major factors determining the magnitude of ammonia losses from surface applied liquid swine manure.

SWEDEN

Detailed laboratory and field studies of NH_3 volatilization from manure provided the following conclusions:

- * the potential for ammonia volatilization increases threefold when soil temperature increases from 14 to 24°C,

- * solid manure is subject to greater NH_3 losses than liquid manure. *Note: That conclusion was based on work with various slurries. The slurries with most solids had least soil contact and hence more volatile loss. The conclusion from this study could not*

be extrapolated to comparison of liquid hog manure where much of the N is as ammonium and solid beef feedlot manure where half or less of the N is as ammonium.

* for liquid manure, shallow injection or immediate incorporation greatly reduced ammonia losses (Svensson 1994).

The Swedish study provided the following summary statement "Taken together, the results of the present study and from the literature data suggest that minimum ammonia volatilization from land-spread livestock manure can be expected when incorporating easily flowable slurry at low temperature, high air humidity and low wind speed into a well cultivated soil of high cation exchange capacity" (Svensson 1994).

The ultimate in avoiding volatile losses of ammonia is to have effective soil injection of the manure. Saskatchewan is at the leading edge of work to achieve effective soil injection of liquid manure, including low soil disturbance systems (Hultgreen 1999).

4. Manure Applications and Soil Salinity

NOTE: The information for this section came mostly from a paper presented to the pre-conference workshop of the June, 1999 Manure Management Conference in Saskatoon (Henry 1999). Additional references were encountered in completing this literature review and the relevant information has been added to the 1999 paper.

SUMMARY

* **Beef feedlot manure from feedlots that use no bedding is a much different product than the farmyard manure on which original recommendations were made. The salt and nutrient content of manures must be utilized as the basis for setting safe rates of application for long term annual applications.**

* **Liquid hog manure has the potential to salinize land, but problems can be avoided by treating it as a fertilizer and applying the fertilizer based on major nutrient analysis and in relation to crop requirements.**

* **The $\text{NH}_4\text{-N}$ content of liquid hog manure can be easily determined in the field by measuring the EC of the manure.**

* **Where high SAR groundwater is used in hog operations the Na content of the manure will be high, but the SAR will be up only slightly. Some high manure Na value have also been found where the water used in the barn has a low SAR suggesting that ration is also important. Most manure SAR values measured to date suggest that there should be no problem, but a few high SAR values have been encountered as a precautionary measure a program should be launched to sample soils that have received many annual applications of liquid hog manure where the water source for the operation is the Judith River Formation. The study should**

include an investigation of hog operations that produce high SAR manure to determine the role of water and ration in producing a high SAR.

4.1 Solid Beef Feedlot Manure

Farmyard manure and soil salinity have had a long and harmonious relationship. For decades we have recommended the application of farmyard manure to alleviate the effects of excess salts in the soil. In most cases the manure was mostly straw. The positive effects noted were probably due to reduced evaporation from the surface mulch of manure, or an increase in water holding capacity because of the large amount of organic matter added in the manure.

Long term manure studies were conducted at Ag Canada Research Stations at Indian Head and Melfort (McIver *et al.* 1978). The Indian Head study had rates up to 10 T/acre applied every 3 years and the Melfort study had 15 T/acre applied every fifth year. Crop yield increases from manure were small at first but cumulative effects became large after about 10 years. Soil P levels also increased after manure application, a result that is repeated in all manure application experiments.

The appearance of beef feedlots with high populations of animals and different management puts the issue in an entirely different context.

In California, (Pratt 1984) found that soil salinity increased from 1 to 3.5 mS/cm (sat.paste) with the annual application of 64 T/ac of solid feedlot manure for 4 years.

A recent Colorado study sampled irrigated soils that were close to feedlots and had received annual manure applications of 18 to 35 T/acre for several years (Davis *et al.* 1997). For clay loam soils EC values up to 2.5 mS/cm were found. The study concluded that repeated manure applications had not increased salinity to problem levels, but that the potential to do so in the future was greater on heavier textured soils.

In Minnesota two successive applications of 90 T/acre of solid beef manure increased surface soil saturated paste EC from 0.5 to 2.5 mmhos/cm and extractable Na from a few ppm to 150 ppm (Evans *et al.* 1977). The Na level decreased over time as it was leached to lower soil levels.

A recent Australian study examined the effect of feedlot cattle drinking water and ration Na level on the manure EC and Na level (Sinclair *et al.* 1996). The relationships established were as follows:

Fresh Faeces EC and Water EC : $r^2 = 0.35$

Fresh Faeces Na and Water Na : $r^2 = 0.59$

Fresh Faeces Na and Ration Na : $r^2 = 0.44$. The average Na level of the water was 212 ppm but the average Na level of the ration was 1090 ppm. The study concluded that:

* salinity contents of drinking water should be taken into account by nutritionists when formulating rations and

* Ration Na levels in many feedlots appear high and should be reduced (Sinclair *et al.* 1996).

The most relevant data to this review is the long term study on feedlot manure that was initiated at Ag Canada Lethbridge by Theron Sommerfeldt and colleagues in 1973.

Prior to starting the Lethbridge experiments soil samples were taken from farm fields that had received feedlot manure for decades. From that study it was concluded that annual rates of manure of 28 T/acre for 40 years did not result in an undesirable buildup of N, P or soluble salts in the soil (Sommerfeldt *et al.* 1973).

The experiments started at Lethbridge in 1973 used feedlot manure from a feedlot in which **no bedding was used**. The annual rates of application of manure were 30,60 and 90 T/ha for a dryland experiment and 60,120 and 180 T/acre for an adjacent irrigated experiment. After 11 years of annual applications the maximum soil salt content was as shown in Table 2. The soil EC is for the saturation extract.

Table 2. Soil salt content after 11 years of annual application of beef feedlot manure (Chang <i>et al.</i> 1991)			
DRYLAND		IRRIGATED	
Manure T/ha	Max Soil EC mS/cm	Manure T/ha	Max Soil EC mS/cm
0	0.8	0	0.8
30	2.0	60	2.6
60	3.1	120	3.5
90	3.2	180	4.1

For the dryland experiment the maximum EC was at the soil surface but for the irrigated experiment the maximum EC was at the 30-60 cm depth.

The possibility of **sodicity** problems by manure additions was also examined from the Lethbridge data. There was a very slow but linear increase in SAR from manure additions indicating a potential for the soil to become sodic in the distant future. However, under irrigation, the specific annual rates of increase of SAR were lower as time went on indicating that it could take a **very long time for annual applications of manure to make the soil sodic** (Chang *et al.* 1990).

The Lethbridge experiments have been extensively reported in the scientific literature (Chang and Entz 1996; Chang and Janzen 1996; Chang *et al.* 1990; Chang *et al.* 1991; Chang *et al.* 1993; Chang *et al.* 1994; Dormaar and Sommerfeldt 1986; Sommerfeldt 1978; Sommerfeldt and Chang 1985; Sommerfeldt and Chang 1987; Sommerfeldt *et al.* 1988; Sommerfeldt *et al.* 1973). After the exhaustive work it has been concluded that long term annual application of manure at the maximum recommended rates (30T/ha dryland and 60T/ha irrigated) is not advisable because of soil and water contamination problems.

The key to maintaining a sustainable system appears to be in maintaining some approximation of major plant nutrient balance between what is applied and the uptake by crops. The Lethbridge experiments were with feedlot manure with no bedding and very high nutrient content. The original maximum annual applications were probably based on a different product with a much higher straw and much lower nutrient content.

4.2 Liquid Hog Manure

4.2.1 Findings Elsewhere

The fact that the liquid hog manure has a high EC value immediately raises concern about the possibility of salinizing soils by land application of the manure.

A laboratory study in **Spain** showed that it was possible to quickly salinize a soil with pig slurry with an average EC of 11.6 mS/cm and SAR of 3.1 (Bernal *et al.* 1992). However, their rate schedule started at 18000 gallons/acre/yr and went up to 89000 gallons/acre/yr. It was not surprising that they concluded that in arid and semi-arid areas rates of pig slurry should not exceed 18000 gallons/ac/yr.

A field study in **Belgium** found an increase in soil salinity from application of 18000 gallons per acre for two years on the same land that had received from 4000 to 9000 gallons /acre for many years (DeSmet *et al.* 1991).

In **Delaware**, 3 consecutive years of liquid poultry manure application at 20000 gallons /acre increased soil salinity (sat. paste) from 1.9 to 7.6 mS/cm and reduced corn yields (Shortall and Liebhardt 1975). The EC of the manure was not stated but the highest rate would have provided 528 kg/ha of N in each of the 3 years.

Work at Purdue University in **Indiana** has examined the effect of **salt** content of a **swine ration** on the Na level of the manure, Na level of corn grown on manure amended soils and on soil Na accumulation (Sutton *et al.* 1976; Sutton *et al.* 1978; Sutton *et al.* 1984). Where the salt content of the diet was 0.2 % the Na content of the liquid manure was 172 ppm but when the salt content of the diet was 0.5% the Na content of the manure was 439 ppm (Sutton *et al.* 1984).

The Purdue University field studies were on silt loam and silty clay loam soils with the maximum annual Na loading at 119 kg Na /ha /year for 3 consecutive years. Those Na levels did not increase the Na content of corn leaves but did increase the exchangeable Na content of the soils. Despite the Na accumulation in the soils, there was enough leaching and plant uptake to prevent a salt toxicity problem. It should be noted that the three manure rates used in the Purdue study supplied about 300, 600 and 900 kg N /ha /year (Sutton *et al.* 1984).

North Carolina has undergone considerable increase in hog population in the recent past and receives much publicity about problems that have arisen. Experiments in the literature include data where annual N applications from swine manure are as high as 1000 kg N /ha/year and some of these treatments include annual Na additions of 1000 kg Na /ha /year (Burns *et al.* 1987). In those experiments annual crop removal of Na by Coastal Bermudagrass was only about 29 kg Na /ha so considerable excess was left in the soil.

Despite the large annual Na loading rates and limited crop uptake, the soil accumulation of Na was not large. The quantity of cations applied in the manure was in the order K>Ca>Na>Mg but the order of retention in the soil was K>Ca>Mg>Na (King *et al.* 1990). It should be noted that the average annual March to November **precipitation is 36 inches** at the location of the **North Carolina** experiments so that data is of little relevance to the Saskatchewan situation.

4.2.2 Liquid Hog Manure in Saskatchewan

A recent study of the chemical composition of Saskatchewan manures included 72 manure samples from 15 different hog manure lagoons in several areas in Saskatchewan (Fayne 1997). The major plant nutrient values found in that study formed the basis of the current extension bulletin on the topic (Sask Ag and Food 1997). Table 3 shows the nutrient content for liquid hog manure from the bulletin:

Table 3. Nutrient content of liquid hog manure in Saskatchewan		
Nutrient	Average lbs/1000 Imp.gallons	Range
N	30	12-44
P	10	1-26
K	13	7-20
S	2	1-7

It should be noted that the data are given in terms of elemental N, P, K and S. To get P₂O₅ values multiply P values by 2.29 and to get K₂O values multiply K values by 1.21.

The data show a wide range of values. However, the variation is mostly from site to site and not within the same lagoon. In the Bayne study, 5 separate samples of liquid manure were taken after agitation and from the application tank. In general the 5 separate samples taken as the material was being applied gave very uniform results for chemical constituents.

Salt Content of Saskatchewan Liquid Hog Manures

The Bayne study also measured EC and major salt components of the samples. Table 4 provides a summary of that data.

Table 4. Salt content and composition of Saskatchewan liquid hog manures.(from data of Bayne,1977)

	Average	Range
EC, mS/cm	18.5	11.9-26.8
Na, ppm	600	300-1000
Ca, ppm	1500	100-5500
Mg, ppm	600	100-2100
K, ppm	1300	100-2000
NH ₄ , ppm	2400*	1400-4000
Cl, ppm	1200	600-3600
SO ₄ , ppm	300	100-700

* NH₄ is NH₄-N x 1.28

The overall salt content is 18.5 mS/cm. Recall that intertill aquifers in Saskatchewan have a salt content of about 2.0 mS/cm and seawater is about 35 mS/cm. Therefore, the salt content of the liquid hog manure is high and indiscriminate application at very high rates would cause soil salinization.

When people talk about irrigating with liquid hog manure they simply do not understand the product they are using. Injecting liquid hog manure into an irrigation system, as is done with 28-0-0 liquid fertilizer, is an excellent way to distribute the nutrients in liquid manure. But, **direct irrigation application of undiluted liquid hog manure is not an option**. For this reason, considerable caution is required when using big guns for liquid manure application.

The individual ions that make up the total salt load is also of interest. The dominant cation in liquid manure is NH₄. Calcium and potassium are significant components and chloride is a significant part of the anions. As bicarbonate was not determined, ion balance cannot be determined.

The fact that NH₄ is such an important part of the salt content raises interesting possibilities about using EC measurement to estimate the NH₄-N content of the manure. The data in Table 5 show clearly that EC measurement can indeed be used as an accurate measure of the NH₄-N content of liquid manures.

Table 5. Relationship between EC and NH₄-N content of liquid manures
Elite Stock Farm , Outlook ,Sask. 1993-96 (Henry,1997) NH₄-N ,ppm= -282+152(EC,mS/cm) R² =0.95
North Carolina ,4 years ,4 hog and 2 poultry lagoons (Westerman,1990) NH₄-N ,ppm= -301+132(EC,mS/cm) R² =0.99
Saskatchewan 1996, 70 hog samples from 15 lagoons (Bayne,1997) NH₄-N ,ppm= -446+127(EC,mS/cm) R² =0.87
Saskatchewan 1996 , 15 lagoons (Bayne,1997) NH₄-N ,ppm= -367+121(EC,mS/cm) R² =0.91
Spain 1992 , 8 hog slurries (Bernal etal,1992) NH₄-N ,ppm= -490+184(EC,mS/cm) R² =0.87
Envirotest Labs 1998-99 , 32 liquid hog manure samples NH₄-N ,ppm= -15+155(EC,mS/cm) R² =0.66

For 5 of the 6 equations in Table 5, the relationship between EC and NH₄-N is almost identical. The data are from such diverse locations as Saskatchewan, North Carolina and Spain and even include some different classes of livestock. The Envirotest labs dataset has a lower R² value because several of the samples had total suspended solids approaching 10% and hence were not true liquid manures.

For true liquid samples the NH₄-N makes up 70% or more of the total N. Therefore, if we can predict the NH₄-N content by measuring EC, we can also treat the liquid hog manure as a true liquid fertilizer and accurately determine rates of application to insure that N is not a limiting factor in crop production.

A recent study of liquid hog manure in Manitoba has also shown that about 70% of the N is in the ammonia form and that quick tests in the field can be used to determine the ammonia content (Cavers 1999).

The data in Table 6 use the Saskatchewan equation to determine the $\text{NH}_4\text{-N}$ in lbs/1000 Imp. gallons from the EC of the manure.

Table 6. Using EC to determine $\text{NH}_4\text{-N}$ content of liquid hog manure.	
EC mS/cm	$\text{NH}_4\text{-N}$, lbs/1000 Imp. Gallons
10	8
12	11
14	13
16	15
18	18
20	20
22	23
24	25
26	27
28	30
30	32

Examination of Table 6 shows that as a useful first approximation the $\text{NH}_4\text{-N}$ content of manure in lbs/1000 gallons is about equal to the EC of the manure in mS/cm.

Some precautions will be necessary for manures with high solids but for truly liquid samples, field staff could easily be trained to measure EC on each truck load delivered to a field. EC measurements can be quickly and accurately determined in the field. The author of this document has been measuring EC routinely in the field since the beginning of the soil salinity program in 1982.

Concern Re: High Sodium Water Supplies to Hog Barns

As intensive hog operations develop in Saskatchewan a significant operational problem is finding an adequate supply of water with quality suitable for hog nutrition. In many parts of southern and western Saskatchewan the Judith River Formation is the only reliable water source.

Judith River Formation is bedrock (pre-glacial) and aquifers in it contain soft water usually of the sodium chloride type. The EC of Judith River can vary from as low as 1500 uS/cm (Consul area) to as high as 10,000 uS/cm (Outlook area) but the modal concept is an EC of 2000 to 3000 uS/cm. Almost all of the cations in most Judith River waters are Na so a high SAR is the norm. The SAR of Judith River water is usually in the 50 to 60 range. Any time an SAR is above 10 there is a concern about possible soil permeability problems if the water is used for irrigation.

The Bayne, 1997 data included analysis of the water supply that went in to making up the liquid hog manures. Table 7 shows the relationship between water and manure for the 15 hog lagoons in the Bayne study.

Table 7. R ² values for water vs manure for 15 hog lagoons	
Parameter	R ²
EC	0.05
Na	0.88
Ca	0.11
Mg	0.09
Cl	0.05
SO ₄	0.03
SAR*	0.47

* SAR = $\text{Na} / ((\text{Ca} + \text{Mg})/2)^{0.5}$ with concentrations expressed as milliequivalents per litre.

The total salts (EC) and Ca, Mg, Cl and SO₄ in manure are not affected in any way by the type of water used in the hog operation. This is to be expected because most of those mineral elements would come from the barley etc. that is fed to the animals. However, the Na content of the manure is very closely related to the Na content of the water. The relationship between water SAR and manure SAR is statistically significant but only about half of the variation in manure SAR is explained by variation in water SAR. This is to be expected because SAR is the relationship between Na and Ca + Mg. Because Ca and Mg in manure are not related to Ca and Mg in the water, the SAR relationship would be much lower than that for Na alone.

Jeff Schoneau provided the author with a summary table of chemical analyses of 68 liquid hog manure samples from lagoons at Perdue, Dixon, Lanigan, Burr, Englefeld, Star City, Melfort, Loon Lake and Leroy. The Na values ranged from 256 to 1006 ppm. The Lanigan and Leroy sites had Na values in the 900 to 1000 ppm range with SAR values of 8.6 to 10.3. Water analysis is not available for the wells used by Lanigan and Leroy barns but the author is familiar with the Hatfield Valley Aquifer in that area and the water has EC of 2000 to 4000 mS/cm and SAR values of about 5 to 6.

Recent data from southwest Saskatchewan has shown liquid hog manures with SAR values as high as 28 (Weiterman *et al.* 2000). Examination of the detailed cation data from that study shows the Na levels are about 1000 ppm but the high SAR is because the Ca is only 77 ppm and the Mg is only 44 ppm. Further work will be required to determine the reason for the high SAR values and to determine how widespread such values are.

5. Manure Nutrient Loading Rates

SUMMARY

Excess N from manure can result in nitrate accumulation in soils and leaching to aquifers used for drinking water. High nitrate drinking water can cause methemoglobinemia in babies. Excess P can accumulate in soil and move by erosion to surface water bodies and lead to eutrophication.

The N : P₂O₅ ratio of common crops is about 2.3 :1 but the N: P₂O₅ ratio for most livestock manures is 1:1. Therefore, over the long term, continual manure application to land will result in an accumulation of soil P even if the N is matched to crop removal.

In most jurisdictions loading limits are related to N at first and later the limits are based on P. Limits based on P are required where well developed drainage patterns deliver runoff from fields to sensitive water bodies.

It is unlikely that P limits will be needed in Saskatchewan in the near future. If it is needed in the future, it should be applied to areas draining directly to sensitive water bodies.

If P based soil loading limits were considered for Saskatchewan, a first approximation would be to limit further P additions to crop removal when soil test P in the 0-15 cm depth exceeds 60 ppm and to not apply any manure when soil test P in the 0-15 cm depth exceeds 100 ppm.

It is more likely that N limits will serve Saskatchewan the best.

Suggested annual manure N loadings for Saskatchewan are as follows:

Soil Climatic Zone(s)	Annual N rate (lbs N /ac)
Dry Brown	50
Brown	60
DarkBrown & Moist DarkBrown	70
Black & Moist Black	80
Grey	90
Irrigated	100

Suggested soil test limits for land receiving manure in Saskatchewan are as follows:

Soil	Soil Nitrate N Limit lbs/acre, 0-1 foot
Browns & Dark Browns	75
Blacks	100
Grey	125
Irrigation	150

5.1 Discussion of the Use of N or P Based Loading Limits

In most jurisdictions the first concern is for excess soil nitrate-nitrogen which is subject to leaching. If the nitrate reaches aquifers which are accessed for drinking water there is a health concern, particularly for methemoglobinemia in infants. High nitrates in wells and infant mortalities have been known in Saskatchewan since at least 1948 (Robertson and Draycott 1948). Because of the concern for drinking water nitrate, limits of manure application have historically been based on upper limits for N applications.

The N : P_2O_5 ratio of common crops is about 2.3 : 1 but the N : P_2O_5 ratio for most livestock manures is 1:1. Therefore, over the long term, continual manure application to land will result in an accumulation of soil P even if the N is matched to crop removal. When the Sask. Soil Testing Lab began operation in 1966 it was soon determined that P soil tests that were "off scale" could almost always be related to successive and long-term manure applications.

High soil P values are not of concern to crop production but can be a concern if erosion occurs and the high P soil ends up in a sensitive water body. In humid environments P can also be delivered to water bodies as baseflow from unconfined aquifers. In some humid areas that is a major mechanism by which P ends up in streams and rivers. In the Assiniboine Delta Aquifer area of Manitoba baseflow to streams is also important but there are few situations in Saskatchewan where baseflow is large component. In a river or lake the high P results in eutrophication and the growth of algae that fouls the water for domestic consumption.

In Saskatchewan we have always considered that P is immobile in soil and not subject to leaching. However, for sandy soils with low P fixation capacity and for very high manure rates P can become mobile. For medium and fine soils in Saskatchewan P leaching will not likely be a problem. For example on the Sutherland clay soil of U of S farm on Preston Avenue, Saskatoon soil P levels have reached more than 200 ppm and no movement below two feet has occurred (unpublished data of the author).

The use of P as the limiting factor for manure applications has the most relevance in areas where farmland drains directly in to sensitive water bodies or baseflow from unconfined aquifers occurs. In much of Saskatchewan the drainage is to the nearest slough with no delivery to sensitive water bodies. **In summary, it is unlikely that P limits will be needed in Saskatchewan in the near future. If it is needed in the future, it should be applied to areas draining directly to sensitive water bodies.**

5.2 Review of Literature

Loading rates for N and P from manure and the possibility of legislated limits has been the subject of many scientific papers in the past decade. The following information summarizes the data from a broad cross-section of environments and jurisdictions.

The situation in European countries provides a useful starting point and Table 8 is from a recent paper that summarized loading rates for N and P.

Table 8. Annual loading rates (kg/ha) for N and P₂O₅ for arable crops. (Source: Spaepen <i>et al.</i> 1997)		
Country	N	P₂O₅
Belgium	170	100
Denmark	139	27
France	200	-
Germany	160-240	120-210
Italy	600	700
Spain	100	70
The Netherlands	-	110
UK	250	230

The first point to be made from Table 8 is the large difference between countries in the allowed loading limits. The Italian data was based on a personal communication and is obviously not sustainable. The most restrictive limit is the P₂O₅ limit in Denmark. The ranges in the German data represent different regions of the country.

The second point from Table 8 is that limits based on P₂O₅ additions are more restrictive than limits based on N. However, except for Denmark, the differences between N and P₂O₅ are not large.

A recent paper from The Netherlands has examined the changes that have taken place in P₂O₅ loading limits over the past decade (Jongbloed and Lenis 1998). For arable land the limits have declined only slightly (from 125 kg/ha P₂O₅ to 110 kg/ha) but for grassland the limits were reduced by a factor of 2 and for corn silage by a factor of 3.

Problems with nutrient balance in Dutch soils have been recognized since the early 1970s and legislation was passed in 1984 to limit N and P additions from manure (Jongbloed and Lenis 1998). The 1984 legislation used the following criteria:

- * ground water nitrate should not exceed 50 mg/l
- * surface water nitrate should not exceed 10 mg/l
- * surface water should not contain more than 0.02 mg NH₃-N per liter
- * from 1992 all manure pits should be covered
- * Ground and surface water should not exceed 0.10 mg of ortho-P per liter (about 0.15 mg of total P per liter). Local authorities could further reduce the allowable concentrations, especially when the farms are located close to woods or natural parks.

In 1998 The Netherlands introduced a compulsory nutrient accounting system for farms with more than 2.5 livestock units per hectare. The farms must supply an annual accounting of N and P entering and leaving the farm. The allowable surplus of P_2O_5 will decrease from 40 kg/ha in 1998 to 20 kg/ha in 2008 (Jongbloed and Lenis 1998). The Netherlands situation shows how restrictive regulations can become if a system is allowed to accumulate large nutrient surpluses in the soil for an extended period.

The issue of **P as the rate limiting factor** in manure application has received considerable attention in Europe in the past decade. **A workshop was held in Ireland in 1997** and the proceedings have been published in a book which is a major document dealing with all aspects of P testing of soils (Tunney *et al.* 1997).

An experiment at Broadbalk established a sharp breakthrough point of **60 ppm** available P, beyond which significant leaching losses of P occurred (Heckrath *et al.* 1995; Heckrath *et al.* 1997).

A separate UK study has established a close relationship between P balance (soil application minus crop removal) and soil available P with R^2 values as high as 0.94 for a 0-30 cm soil sample (Smith *et al.* 1998). They concluded that **leaching losses of soil P** would not be excessive if topsoil available P was restricted to **70 ppm**. They also pointed out that the lack of proper crediting of P in manure additions leads to soil accumulations and eventual problems with eutrophication of surface water bodies.

The work of Smith *et al.* has pointed out that over the **long term manure and fertilizer P** can be considered as **equivalent** (Smith *et al.* 1998). Earlier research based on short term experiments emphasized the lower efficiency of manure fertilizer in comparison to inorganic fertilizer, but over the longer term the two become equal.

For various US states:

- * **30 ppm** soil available P is taken as adequate for crop production and at that point applications should be **limited to crop removal** and
- * **60 ppm** soil available P is set as the upper limit at which further **additions should cease** until the soil test is reduced (Sibbesen and Sharpley 1997)

A recent symposium overview on phosphorus and eutrophication summarized the issue for the U.S. as follows:

- * If P is to be used as a limiting factor the P-sensitive water bodies should be identified
- * threshold soil P levels should be established. The paper reported threshold soil P levels at from 30 to 60 ppm depending on the state (Daniel *et al.* 1998).

5.3 Information From Specific States of the US

IOWA

Iowa adopted manure management **rules in 1995** and ILOs with an animal weight capacity of 90,800 kg must submit a manure management plan to obtain a construction permit (Jackson *et al.* 2000). The recent Jackson *et al.* paper reported on a study conducted in a 6 square mile area of intensive hog operations. They found that the manure management **plans required audit**. The 'nutrient books' were balanced on paper by underestimating manure N content, projecting above average crop yields, applying manure to soybeans, overestimating field sizes and claiming the same field by more than one ILO (Jackson *et al.* 2000). If they used **P** as the limiting factor for application area, the data showed that the **land base available was only about 10% of the actual requirement**.

WISCONSIN

A common buzzword phrase in manure management in recent years is BMPs (Best Management Practices). The idea is to establish some code of practice described in terms of BMPs and all the potential environmental hazards will disappear.

A very recent study in Wisconsin surveyed 1,928 farms to determine nutrient application rates and the use of BMPs (Shepard 2000). They found that **2/3 of the farms apply excess N and 80% apply excess P** for corn production and that few use the BMPs in an appropriate fashion. Very large nutrient excesses were present on only a few farms, but complete adherence to BMPs was uncommon. They concluded that to be effective, BMPs must be devised with input from farmers from the outset (Shepard 2000).

NORTH DAKOTA

North Dakota Department of Health requires ILOs to obtain **approval to operate** and farms with more than 1000 animal units must keep a record of manure applications. A recent survey of 365 ILOs showed that **only 1/3 had obtained approval to operate**. Only half of those with approval to operate kept application records and only 1/4 of those without approval kept records (Birchall and Klrnow 1999).

OREGON

For corn production on dairy farms in Oregon the use of the pre-side dress soil nitrate test is considered the most definitive (Hart *et al.* 1997). They further recommended a "report card soil test" after harvest to determine if N application had been excessive. If a **one foot soil sample shows > 15 ppm $\text{NO}_3\text{-N}$** after harvest, N was supplied in excess of crop need. **Note: 15 ppm on a one foot sample = 60 lbs N/acre.** They also used a corn stalk nitrate test at harvest time and a value of **>5000 ppm $\text{NO}_3\text{-N}$** would require reduction in future N applications (Hart *et al.* 1997). In their survey work of Oregon dairy farms they found that **soil $\text{NO}_3\text{-N}$ was greater than crop need in about 40% of the cases.**

Survey of University Faculty of 43 US Universities

A recent survey of faculty from 43 universities in the US established the current situation with respect to manure nutrient crediting and regulation of ILOs (Schmitt *et al.* 1999). That study reported:

- * **Proper credit** of manure nutrients is conducted by **37% of swine** operations but only **18% of beef** operations
- * Manure N crediting has greatly **improved over the past 5 years**
- * **Improvement** in manure N crediting is primarily **because of regulation** - either existing or pending - education, awareness, economics and peer pressure have little effect
- * **More states** will regulate ILOs via a **permitting process** in the future

* In the 1990s P issues have escalated in importance re: environmental issues. While N has been the focus of nutrient balancing in the past, P is now becoming more important.

5.4 Saskatchewan Perspectives on Nutrient Loading and Information from Manitoba and Alberta

Nitrogen

The current system of permitting ILOs in Saskatchewan requires a nutrient management plan based on nitrogen loading by manure and crop uptake of N (Sask Ag and Food, Workbook and Application Form for the approval of ILOs). The system is based on estimating yield potential for various rainfall probabilities and matching manure N applications to the crop N requirement. The basic data used was that provided by the Soil Science Department, University of Saskatchewan which forms the basis for recommendations by Envirotest Labs (formerly Sask. Soil Testing Lab.). The suggested yield goal to use in calculating N requirements is that associated with the 25% rainfall probability.

Utilizing the current crop nitrogen requirement guidelines with additional interpretation and simplification by the author leads to loading limits suggested in Table 9.

Table 9. Suggested annual manure N loading rates for Saskatchewan	
Soil Climatic Zone(s)	Annual N rate (lbs N /ac)
Dry Brown	50
Brown	60
DarkBrown & Moist DarkBrown	70
Black & Moist Black	80
Grey	90
Irrigated	100

The above N rates may seem low, but it must be remembered that they are designed to accommodate annual applications into the foreseeable future. In a series of dry years even the above low rates would result in nitrate accumulation in the soil. It is without doubt that a few annual applications can exceed those values by three times or more, but for on going annual applications the rates must be reasonable to avoid accumulation.

The annual limits are not based on the same application each year but the average over a series of years. With liquid hog manure it is not feasible to make an application of 50 lbs N/acre in a single year. In practice 100 or 150 lbs N/acre will be made every two or three years.

For a new ILO with applications to fields low in N the above rates would well be too low for maximum yield in a high rainfall year. Therefore, the first few applications in a new ILO should exceed the long term annual limits to insure adequate N for the crops. In the early days of stubble fertilizer recommendations, the N fertilizer rate recommended in the Brown soil zone was set based on average rainfall and very low N rates were recommended. As experience was gained the rates were increased to a level that would insure a reasonable yield in a good year. The original very low N recommendations were described in extension events by this author as "designed to guarantee a crop failure whether it rained or not"

The above loading limits are based on repeated annual applications and do not address the concept of a single application loading limit. In practice many new Saskatchewan ILOs have a system of applying larger N amounts in the first year in anticipation that a repeat application will not be made for 3 or more years. For example, Heartland Livestock Ltd. has often applied 150 lbs N/acre in the first year with the anticipation that a repeat application would be made in 3 years. The demand for manure application to land has been such that at many locations repeat applications will not take place for 6 years (Braithwaite 2000).

The most practical way to balance the books is to use annual soil testing for N to monitor the N balance between addition and crop removal. Manitoba and Alberta have established such limits and they are presented in Tables 10 and 11 and proposed Saskatchewan limits are presented in Table 12.

The province of Manitoba deals with N loading by utilizing annual soil tests on fields receiving manure (Table 10).

Table 10. Nitrogen soil test limits for land receiving manure in Manitoba. (Source: Personal Communication :Curtis Cavers)	
Crop -Soil	Soil Nitrate N Limit lbs/acre, 0-2 feet
Annual crops -medium to fine textured soils	140
Annual crops - sandy soils	90
Alfalfa-All soils	275
Grass-Alfalfa and grass-All soils	200

In Manitoba the siting of hog barns is left to the Rural Municipalities but Manitoba Conservation controls the manure application through the above N soil test limits. **Annual soil tests are required by law and must be reported to Manitoba Conservation.** The law was just enacted in 1998 so experience is just being gained with it.

The soil test N limits suggested in Alberta are provided in Table 11. The Alberta Code suggests restricting manure application until the soil test is below the limit set.

Table 11. Nitrogen soil test limits for land receiving manure in Alberta. (Source: Alberta Code of Practice, 1998)	
Crop -Soil	Soil Nitrate N Limit kg/ha, 0-2 feet
Medium to fine textured soils Black, Grey or irrigated soils	300
Coarse Black, Grey or irrigated soils	150
Brown & Dark Brown dryland soils	150

The soil test limits set in the Alberta Code are guidelines only with no legislative requirement to follow them. The limits come from the September, 1998 version of the Code. Various revisions of the code exist but it is considered a work in progress until some actual legislated requirements are in place.

Proposed limits for soil test N for Saskatchewan are presented in Table 12. The **one foot depth** is proposed as a standard simply because that is **now the standard** in soil testing in Saskatchewan. The one foot depth was instituted in 1991 after an intensive soil sampling research program that determined the numbers of samples required from a field to get a representative sample. With the one foot depth it is much more likely that a proper sample will be obtained. Where residual N from manure is being traced it is highly desirable to do **duplicate sampling** of individual fields to insure reliable agronomic recommendations. For duplicate sampling the two foot depth is impractical.

Table 12. Proposed nitrogen soil test limits for land receiving manure in Saskatchewan.	
Soil	Soil Nitrate N Limit lbs/acre, 0-1 foot
Brown & Dark Brown	75
Black	100
Grey	125
Irrigation	150

In examining the proposed limits it should be kept in mind that long term average data for soil nitrate-N to 1 foot are as follows:

Stubble = 25 lbs N/acre , 1 foot depth

Summerfallow = 55 lbs N/acre , 1 foot depth.

A recent study of irrigated fields at Outlook showed an average nitrate-N to 1 foot of 129 lbs/acre (Bardak-Meyers 1996).

Phosphorus

NOTE: Where P soil test data in ppm is used it relates to the test used by Envirotest Labs in Saskatchewan.

Recall the earlier statement that it is unlikely that P limits will be needed in Saskatchewan in the near future. If it is needed in the future, it should be applied to areas draining directly to sensitive water bodies.

The issues surrounding residual soil P in Western Canada and the northern US has been well researched and reported (Bailey *et al.* 1977; Campbell *et al.* 1984; Halvorson and Black 1985; Read *et al.* 1977; Read *et al.* 1973; Ridley and Hedlin 1962; Sadler and Stewart 1975; Wagar *et al.* 1986) and the considerable data has been summarized (Roberts and Stewart 1987).

The standard practice of seed placement of small amounts of P fertilizer is based on meeting the immediate crop yields with the least possible investment in fertilizer. It is well known that broadcast applications of low P fertilizer rates are not effective. However, the considerable body of scientific work noted above provided the following observations and conclusions:

- * A very high single application broadcast rates of several hundred kg /ha P_2O_5 , the fertilizer is eventually recovered by plants as residual responses for years after the original application. For example, an application of 365 kg/ha of P_2O_5 on a Sutherland clay soil was completely recovered after 5 years in crops and the soil to a depth of 60 cm (Wagar *et al.* 1986). About 80 % of the applied P was recovered in the 0-30 cm depth of soil.
- * An application of 365 kg/ha of P_2O_5 to a Sutherland Clay soil gave a 0-15 cm depth soil test value of 30 ppm P one year after application (Wagar *et al.* 1986).
- * An application of 900 kg/ha P_2O_5 gave a 0-15 cm depth soil test of 70 ppm on a Waskada clay loam soil in Manitoba (Wagar *et al.* 1986).
- * The general conclusion of a large volume of research on residual P fertilization was that single large applications of P could be as effective as annual small doses in maintaining yields of cereal crops and that **very large rates would be required to saturate the soils capacity to retain the P in the root zone of crops.**

The province of Manitoba considers P in establishing manure management plans but the system is actually 'driven' by the N soil test limits.

Alberta has established P soil test limits as follows:

Moderate Runoff Risk

- * Where soil P is in the 200-250 ppm range in the 0-15 cm depth, manure P should not exceed crop removal unless supported by a nutrient management plan.
- * Where soil P is in excess of 250 ppm range in the 0-15 cm depth, manure P should be less than crop removal unless supported by a nutrient management plan.

High Runoff Risk

* Where soil P is in the 150-200 ppm range in the 0-15 cm depth, manure P should not exceed crop removal unless supported by a nutrient management plan.

* Where soil P is in excess of 200 ppm range in the 0-15 cm depth, manure P should be less than crop removal unless supported by a nutrient management plan.

Again, the P limits are suggestions in the Code with no requirements. **The very high P levels set in Alberta are likely a function of what has already happened in 'Feedlot Alley' and the very high soil test P levels that already exist.** 'Feedlot Alley' is an area a few miles north of Lethbridge with a high density of beef cattle feedlots. The author has driven through 'Feedlot Alley' and for about 15 miles one is never out of the site (or smell) of feedlots.

It is not likely that P based limits will be required in Saskatchewan but if P were used as the basis for nutrient loading a soil test based criteria would appear to make the most sense.

If P based soil loading limits were considered for Saskatchewan, a first approximation would be to limit further P additions to crop removal when soil test P in the 0-15 cm depth exceeds 60 ppm and to not apply any manure when soil test P in the 0-15 cm depth exceeds 100 ppm.

8 Recommendations for Future Work

(1) A high priority for future work should be to deal with the concern in Southwestern Saskatchewan about possible soil sodicity problems from manure where the water source is from wells completed in the high Na Judith River Formation. The study should:

* include input from Sask. Water personnel who are familiar with hog operations in the area

* a first step would be to combine the Bayne data of 1997 on manure composition with the recent (January, 2000) compilation of hog manure data of Jeff Schoneau from samples associated with the Schoneau and Grevers agronomic studies.

* where liquid hog manures with high Na and/or high SAR are identified the individual operation should be studied to determine if water or ration is the Na source

* where high SAR manures are identified and where these manures have been applied for several years to parcels of land, those parcels should be intensively sampled to determine if any problems are developing.

(2) There is no need to establish any long-term study with beef feedlot manure. That work has been done and is ongoing at Lethbridge and does not need to be repeated in Saskatchewan.

(3) There is no need to establish a long-term experiment with high rates of liquid hog manure. It is well known that rates much higher than crop uptake will result in soil and groundwater nitrate accumulation. A single long-term experiment with reasonable rates of liquid hog manure could be beneficial.

The Dixon site of Schoneau already has 4 years data and was established with reasonable manure and fertilizer rates. It could also be desirable to establish a very simple long-term experiment adjacent to the new Elstow location of PSC. Such a study would involve a co-operative project between PSC and U of S and the proximity of locations would keep costs down.

The priority on any longer term study should be to determine how best to apply several years crop N requirements in a single application. The Schoneau work at Dixon is designed to do just that and that type of experiment should be selected for future work.

(4) ILOs that have been in operation for decades should be selected and detailed soil samples taken to determine long-term effects. One or two locations with sensitive hydrologic environments could be selected to determine the nature of contaminant plumes of nitrate from manure.

(5) The work already conducted on EMS structures should be summarized and interpreted before any new studies are commissioned.

(6) The project related to water runoff should be re-focused and integrated with information related to possible human pathogens from manure. The recent events in Ontario should result in such a project being elevated to a high priority.

(7) The engineering work on low disturbance injection and pipeline distribution is of a very high priority. The research and demonstration work on these aspects should receive high priority until such time as the technology is commonplace on land receiving liquid manure.

(8) A protocol should be established for salinity analysis of manure so that the data necessary for sodicity interpretations is available. This will not be a large task. It is a matter of researchers, soil test labs and provincial officials meeting to set down the protocol.

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